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14. ABSTRACT

This project has focused on the development of several new additions to the class of devices known as Interferometric Modulators or IMods. IMods are MEM structures which, by the incorporation of thin film stacks, utilize the phenomenon of interference to efficiently modulate light. The devices are being developed specifically for application to reflective Flat Panel Displays, though many applications outside this area exist. Three new designs were considered based on their ability to provide improved black and white, and color performance. Two of the designs were eliminated based on the complexity of their fabrication and fundamental processing issues. The third IMod design was evaluated via the fabrication of both static displays (black and white, and full-color) and of black and white test devices. The results were quite encouraging and their generation represents the conclusion of this effort.

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Phase II R&D Final Report:

Advanced Interferometric Modulators for High Performance Reflective Flat Panel Displays

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Etalon, Inc.
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Air Force Phase II Final Report

Objectives

The primary objective of this effort was the study of advanced Interferometric Modulator designs for display and general photonic applications.

Status of the Effort

Static displays based on the D4.2 IMod design have been fabricated on both black and white and full-color versions. Dynamic test structures have also been fabricated based on this design. Data has been collected on the optical and electromechanical characteristics of both.

Accomplishments

Figures 1 and 2 are optical micrographs of the active D4.2 test device. Figure 1 shows the device in the driven or bright state. According to theory, and as indicated in the static displays, the bright state should be in the form of a uniform flat response in the visible spectrum. The image, however, reveals significant color variations including white. This results from two factors at work. The first derives from the fact that high residual stress drove actuation voltages to the upper limits of the insulating oxide's performance. The consequence of this is that the membranes are not in a fully actuated state. The second factor is directly related in that the use of high voltages caused undue heating in the devices and resulted in thermally induced warping of the membranes. These issues will be mitigated in the next iteration, however the operating principle is demonstrated in these active devices.

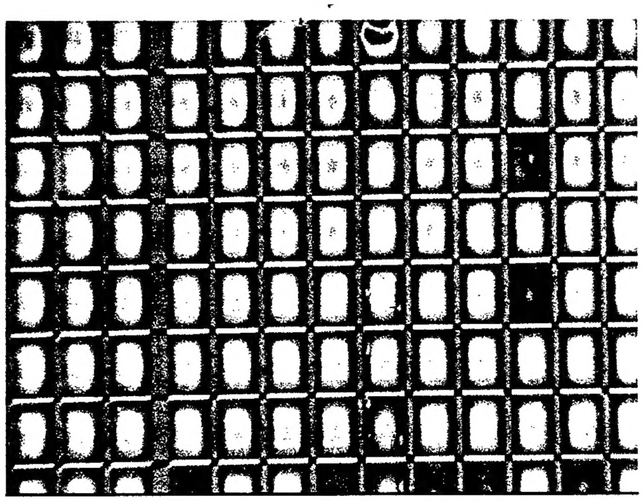

Figure 1: Reveals an optical micrograph of the D4.2 design in the driven or white state. Color variations are due to non-uniform flatness of the structural membrane, and incomplete actuation.

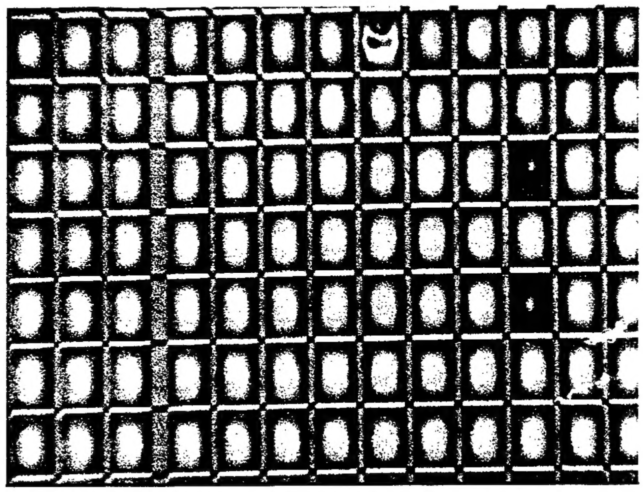

Figure 2: Shows an optical micrograph of a D4.2 test device in the undriven or dark state.

The undriven devices, pictured in figure 2, are shown before the application of a voltage and therefore do not exhibit the thermally induced warping of the structural membrane. The dark state is clearly apparent, though there remains some stress related nonuniformity in the membrane. This results in a net upward bow in the membrane and a trend towards a blue state in the center. Again, fundamental validation of the optical performance of the D4.2 design is shown in an active device.

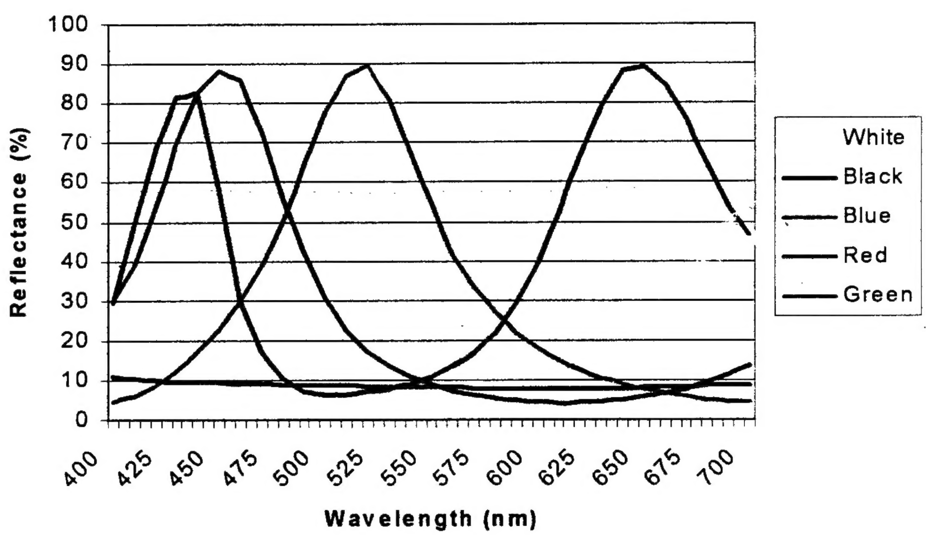

Figure 3: Shows plots of the spectral reflectance function of an actual D4.2 static display. The data compares exceptionally well to results from optical modeling.

Static displays have also been fabricated using the D4.2 stack design. These are manufactured in the same manner in which the original IMod based static displays were built. The initial optical stack is deposited, and sequence of deposition and patterning steps occurs with SiO2 as the solid spacer.

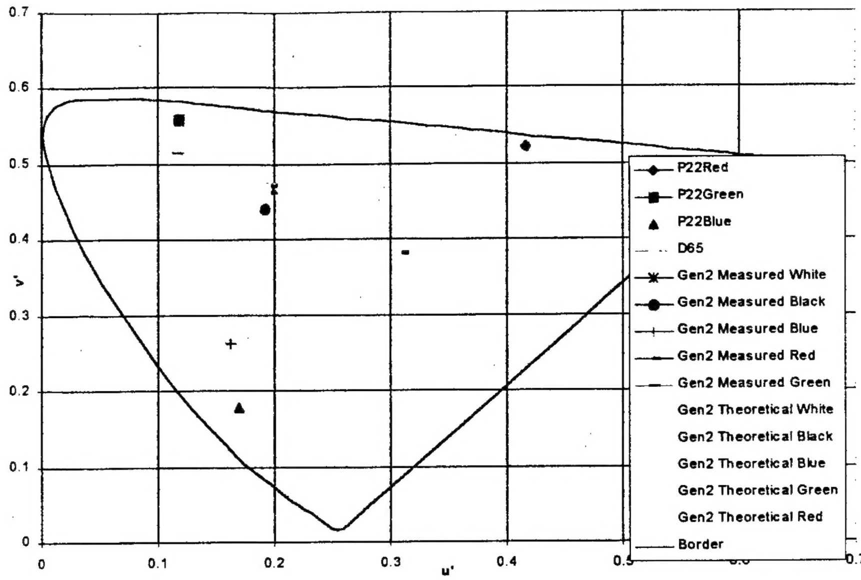

Figure 4: Reveals the color gamut chart of the D4.2 design (measured and theoretical data) as compared to the P22 phosphors. All measured data comes from the static displays.

Optical measurements of these displays have provided data which is quite encouraging. Figure 3 shows plots of the spectral reflectance functions for static displays based on the D4.2 IMod. In general, the peaks have a characteristic that follows quite closely what the optical models predict. The data does diverge from the model in some ways. The dark state and the lower bounds of the color peaks are in general about 5% higher than what would be expected. This is a result that is explained by the front surface reflection of the glass substrate. However, the white state is lower than expected (about 10%), particularly given the front surface. In addition, the maximum color peak values are 5% lower than would be expected given the front surface reflection. Film quality may play a role in both these cases. A lower than expected reflectivity value for the aluminum film, or compromised quality in the optical stack could both be contributors. More precise analytical tools will have to be brought to bear.

Figure 4 shows the color gamut of the static displays as compared to the P22 phosphors. In general, the blue and the green compare favorably though not quite as saturated. The red suffers from the fact that it also incorporates a blue peak. This is a consequence of the fundamental nature of this IMod design and will have to be addressed in future versions. Substitution of alternative metals in the optical stack and/or optimization of the ITO film characteristics may resolve this issue.

Data has also been collected on the fundamental black and white performance of this design. Measurement of the Y values of the reflected performance allows for a determination of the contrast ratio and the data is shown in table 5. Data was taken on display both with and without a front mounted diffuser. Normal usage of an IMod display is expected to require a diffuser in order to

minimize color shift with viewing angle change, and to diffuse what is normally a specular surface. Both non-diffuse and diffuse measurements compare favorably with conventional LCDs whose contrast can range as high as 4:1. The current diffuser is normally used as a backlight diffuser for transmissive LCDs. The incorporation of a diffuser that is optimized for use with IMods is expected to improve diffuse contrast by another 2-3 points.

	Y Value		Contrast Ratio	
	Without Diffuser	With Diffuser	Without Diffuser	With Diffuser
White Sample	56.93	48.80	10.42	6.06
Black Sample	5.47	8.06		

Table 5: Portrays data which has been collected on the black and white performance. Contrast ratio compares favorably with that of conventional reflective LCDs which generally achieve values of 4:1.

Figures 6 and 7 are images of D4.2 IMod based static displays which show the black and white performance. Figure 5 provides a comparison between a "Palm V" using a STN display, a similarly formatted D4.2 static display, and the "Wall Street Journal" which is used as a backdrop. The improved brightness of the IMod display over the "Palm V" is quite apparent. Performance is also improved over the Journal. While not shown in these images, the IMod display exhibits a significantly improved viewing angle performance as compared to the "Palm V", providing as much as an additional 30-40 degrees of increased total viewing cone. The light source in this case is diffuse background lighting from a clear sky.

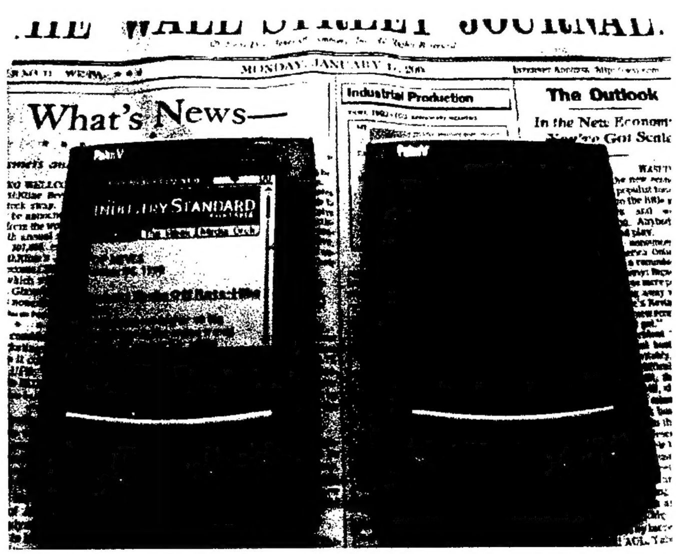

Table 6: Side by side comparison of the static IMod display vs. the LCD display of the Palm V PDA. Brightness and clarity are clearly superior in the static display.

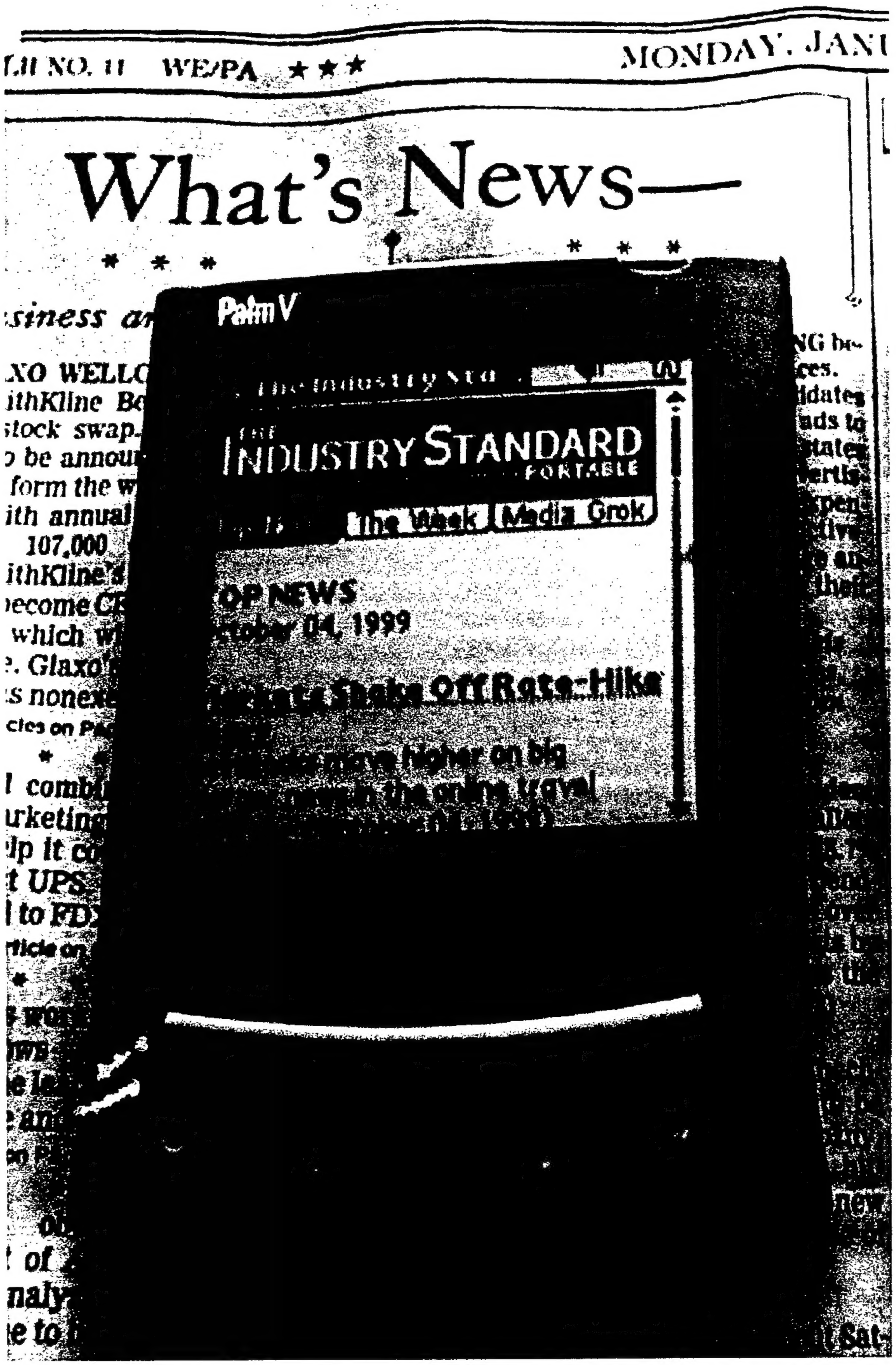

Table 7: Shows a close in shot of the static display against the backdrop of the "Wall Street Journal".

Figure 7 is a high magnification image revealing the resolution of the static display which is patterned to be the equivalent of 170dpi Palm Pilot display. The image is slightly less crisp towards the lower end of the display, a function of the diffuser film which exhibits some viewing angle related performance variation. The reason behind this is not understood at this time. Still, performance is quite good, and a notable improvement over the newsprint medium. It should be noted that there are no color shift phenomena associated with the black and white performance.

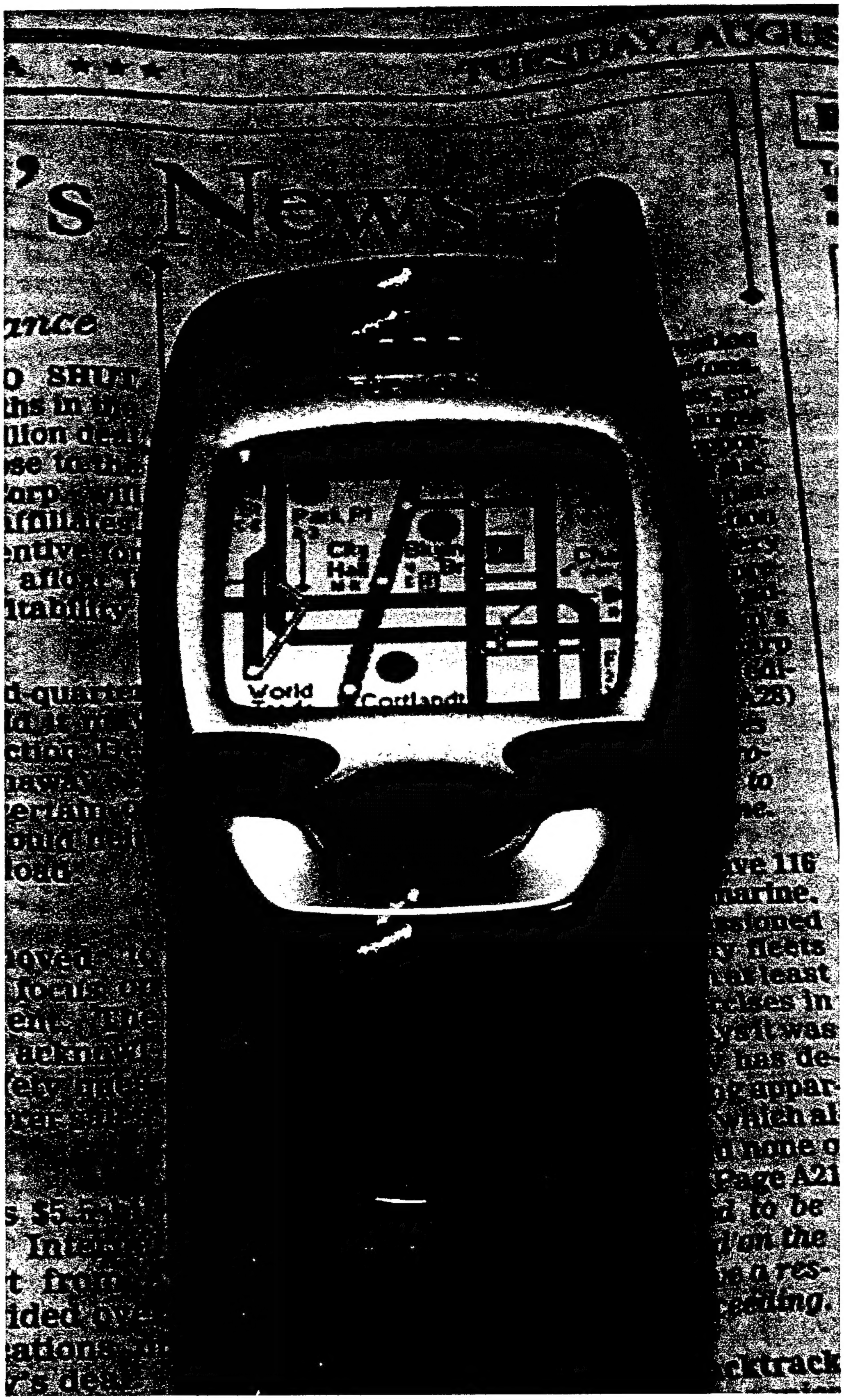

Figure 8: Shows an image of a full-color D4.2 display formatted for a cell phone application. Overall brightness in this display also exceeds that of the Journal.

Figure 8, above, is an image of a full-color static display formatted for a cell phone application. The image shown is of a subway system map.

Summary

In general, this effort has resulted in the fundamental validation of a new IMod design. The design is capable of both black and white, full-color, and black and white plus color performance. This is unlike the original IMod design which is capable of color performance only. Validation has occurred in the form of static displays that provide excellent performance and an accurate representation of the design's potential. In addition, functioning active devices were demonstrated. While issues emerged concerning the electrical and optical performance of the active IMods, their origins are well understood and they are expected to be resolved over the next several runs of IMods. The fabrication process for this design has progressed significantly, requiring as few as 3 masks for a black and white display, and 5 masks for a full-color display. Development is occurring which could remove a mask step from both processes.

Overall, a significant new design has been added to family of IMods optimized for reflective display applications. This will provide at least two approaches for developing display applications based on these devices. The ability to fabricate a display for black and white performance only will add flexibility to any manufacturing development plans by providing a multi-tierd array of offerings with increasing performance. This should significantly enhance the prospects for manufacturing viable products, as well as locating and addressing ready markets for the coming generations of portable electronic products. The bulk of these are expected to require the incorporation of low power, high performance reflective displays.

Personnel supported on this project include:

Mark W. Miles	Principal Investigator
Clarence Chui	MEMS Design and Testing Engineer
Chris Storment	Senior Process Engineer
Erik Larson	Display Design

Interactions

Portions of this work were presented at the Society for Information Display conference held in Long Beach California, May 16-18 2000.

Patent Disclosures

No new patent disclosures have been made.